

least 10 dB above the internally generated noise of the hearing aid and where the aid is not saturated; this caused the individual components of the acoustic output signal of the hearing aid to become perceptible. The measurement was thus made in the position involving maximum radiation, i.e. a worst-case situation.

The hearing aid gain at the frequencies of the harmonics were subtracted from the measured level to obtain the input-related spectrum and overall input-related interference level (OIRIL) determining the immunity level of the hearing aid concerned.

In order to be able to make immediate comparisons between measurements, they were all converted to a field strength of 10 V/m. For this conversion, the relationship 1:2 Db was applied for the field strength and acoustic signal generally used in hearing aids.

4.2 Assessment of interference

Fig. 4.2.1 shows typically occurring field strengths at the position of the hearing aid where there are different distances between the mobile telephone and the hearing aid. It should be noted that the field strengths indicated in the induction field of the GSM telephone, i.e. categories I and II, are subject to great uncertainty as it is very difficult to make an exact field calculation very close to a radio antenna.

Normal voice signals, at a distance of 1 m will have a sound pressure level (SPL) of 65 Db.

Listening tests of persons with normal hearing made in connection with the EHIMA project showed that interference signals with a strength corresponding to an OIRIL SPL of 55 Db seem acceptable. On the basis of this marginal value, the hearing aids were categorized in four classes (in the case of DECT, in two classes) depending on their immunity to the interference signal they had been exposed to.

The marginal values of the said categories are intended only as a guide. The degree of interference experienced by the individual hearing aid user will depend on a large number of parameters, such as the user's hearing handicap, the present tuning of the aid, its orientation in relation to the antenna of the GSM telephone, the immediate output power of the GSM telephone, etc.

Typical field strengths of hearing aid at varying distances from GSM telephone

Typical field strength of hearing aid when DECT telephone is used

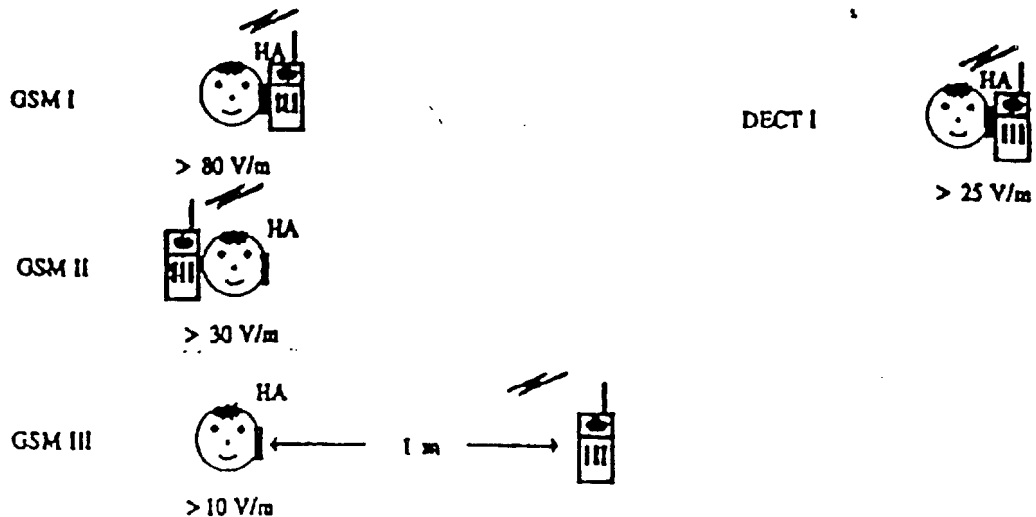


Fig. 4.2.1 Field strength of hearing aid at varying distances from the mobile telephone.

4.3 GSM

Category I covers hearing aids with an OIRIL of 55 dB SPL or less for a field strength of min. 80 V/m, corresponding to the field strength in the immediate proximity of the antenna. In many cases it will be possible to use these hearing aids together with a 900 MHz, 2 W hand portable GSM telephone in the same ear as the hearing aid.

Category II covers hearing aids with an OIRIL of 55 Db SPL or less for a field strength higher than 30 V/m, corresponding to the field strength in the proximity of the opposite ear. Often it will be possible to use hearing aids of this category together with a 900 Mhz, 2 W hand portable GSM telephone in the opposite ear, but not together with a GSM telephone if this is used in the same ear as the hearing aid.

Category III covers hearing aids with an OIRIL of 55 Db SPL or less for a field strength higher than 10 V/m, corresponding to the field strength of a 2 W hand portable GSM telephone at a distance of 1 m from the antenna. Hearing aids of this category will in most situations protect the user against interference caused by other persons using GSM telephones. Hearing aids of this category cannot be used together with a 900 Mhz, 2 W hand portable

GSM telephone, and this also applies if the telephone is used in the ear which has no hearing aid.

Category IV covers hearing aids with an OIRIL higher than 55 Db SPL for field strengths under 10 V/m, corresponding to the field strength of a 2 W hand portable GSM telephone at a distance of 1.43 m. Hearing aids of this category will in many situations display interference from 900 Mhz, 2 W hand portable GSM telephones used by other persons, and users of such hearing aids will themselves be unable to use such a GSM telephone.

4.4 DECT

The output power of DECT telephones is considerably smaller than that of GSM telephones. A field strength of 10 V/m corresponds to the field strength at a distance of 35 cm from the antenna of a DECT telephone. This is why interference will probably occur only in case a hearing aid user wants to use a DECT telephone himself.

No listening tests were carried out to establish the degree of disturbance caused by DECT signals. The immediate estimate is that DECT disturbance is slightly less than that of GSM as the basic tone frequency is somewhat lower and, as such, less offensive to the ear.

Category I covers hearing aids with an OIRIL of 55 Db SPL or less for a field strength above 25 V/m. In many cases they may be used with an 1800 Mhz 250 mW DECT telephone in the same ear as the hearing aid.

Category II covers hearing aids with an OIRIL higher than 55 Db SPL for field strengths under 25 V/m. Users of these types of hearing aid will not be able to use an 1800 Mhz 250 Mw DECT telephone if the telephone is used in the same ear as the hearing aid.

5. MEASUREMENT OF SELECTED TYPES OF HEARING AIDS

5.1. Introduction and objectives

This section deals with immunity measurements made of a selected number of hearing aid types. The selected hearing aids are representative of the types of hearing aid today supplied to hearing-handicapped in Denmark.

The objective of the measurements is to establish the immunity level of hearing aids according to the ruling standard so as to clarify if there are any hearing aid types which are insensitive to signals from either GSM or DECT terminals and to determine, in the case of those hearing aid types which are in fact sensitive to the signals, the distance from a GSM or DECT terminal at which interference occurs.

The complete Laboratory Report is attached as Appendix 1 to this Report.

5.2. Financing

The major part of costs towards the carrying out of the measuring programme was covered by the Danish GSM network operators, Tele Danmark Mobil and Sonofon. Apart from this, the TD-L and TAL laboratories, have contributed some financing.

Through the EHIMA project, hearing aid manufacturers covered the costs involved in the development of the measuring procedure and in listening tests to evaluate interference effects.

Expenses towards the measurement of hearing aids with special interest for Norway were covered by the Norwegian Telecommunications Regulatory Authority (NTRA), whereas a Danish manufacturer of custom-made hearing aids covered his own expenses towards measurement of the hearing aid type concerned.

Finally, members of the working group provided resources for the execution of the rest of the tasks.

5.3. Selection of hearing aid types

The hearing aids to be tested were selected on the basis of the tendering procedure carried out in Denmark every year for hearing aids supplied from clinics. Requests were made to those suppliers who had sold hearing aids following the tendering procedures in 1991, 1992 and 1993, inviting them to supply aids for testing (two specimens of each type). Further, sales figures for the equipment covering the said three-year period were requested.

A Danish manufacturer of custom-made hearing aids supplied to clinics who is not a participant in the tendering contacted at his own request the National Telecom Agency in order to be considered for the testing. This was accepted on the condition that he could substantiate that the aids supplied for the test, as far as immunity was concerned, were representative of the types supplied to audiological clinics. During the phase when data on the selected hearing aids were circulated for comments, the Centre for Equal Treatment of the Handicapped contacted the Group asking if it would be possible for the measuring programme to comprise a body-worn hearing aid.

Based on Norway's participation in the work of the group, the NTRA in Norway selected a supplementary eight hearing aids which are used in that country but not in Denmark or which are supplied in such small numbers here that manufacturers are not invited to submit tenders.

The study comprises a total of 50 hearing aid types (100 aids). It is estimated that every year 50,000 hearing aids are supplied by Danish clinics. Using the sales figures given by the manufacturers, it may be concluded that the study covers approx. 90% of hearing aids supplied in Denmark during the period 1991-1993. The Norwegian figures refer to the supply over a single year, 1993. As far as Norway is concerned, the study of supplementary types covers approx. 85% of aids supplied.

The lifetime of a hearing aid is around five years which means that today there is a relatively large number of aids in use that were supplied before 1991 and, as will be understood, the study does not comprise these. Assuming that there are 200,000 users of hearing aids and a "linear" exchange of hearing aids over five years, it may be concluded that the study covers approx. 76% of hearing aids in use today.

In consequence of this, a considerable number may be expected to be exchanged within the coming 18 months to newer types comprised by the study or to types with better immunity properties.

25% of hearing aids supplied during the three-year period is of the ITE (in-the-ear) type which are primarily used to remedy slight to moderate hearing handicaps. 74% are of the BTE (behind the ear) type whereas body-worn aids total less than 1%. The proportion of ITE equipment supplied by audiological clinics is rising.

Corresponding figures for Norway are: 41% in-the-ear, 59% behind-the-ear and bodyworn less than 1% of the almost 30,000 hearing aids supplied in Norway in 1993.

5.4 Result of measuring programme

The result of the measuring programme is shown in the tables below for GSM and DECT telephones, respectively.

It is a precondition of the correctness of the figures that the immunity of hearing aids measured in the study corresponds to the immunity of aids supplied by clinics and that sales figures given by manufacturers correspond to the number of aids supplied by clinics.

Attention is drawn to the fact that the hearing aid, when situated in the near field of the antenna, is very sensitive with regard to the positioning of the telephone. The immunity figures measured express worst-case situations, as measurements were made with the telephone positioned to give maximum interference. Further, measurements were based on the use of a 2 W hand-portable GSM telephone. In many cases, however, the dynamic power control of the GSM system will reduce the output power of the mobile GSM telephone due to the functioning of the GSM network. In these cases, interference will be correspondingly less.

The tables show accumulated figures; specific figures for hearing aids of a defined category are obtained by subtracting the figure covering this category from the figure covering the closest category which is better.

Example:

The number of hearing aids of category II is required. The number represents those hearing aids which display no interference at a field strength of more than 30 V/m but which are influenced at more than 80 V/m.

Under category II, table 5.4.1, the column has the figure 50540.

Under category I in the same table, the figure 21682 is stated. This figure is deducted from the figure found under category II.

The result indicates that $50540 - 21682 = 28858$ hearing aids of category II have been supplied.

Two abbreviations are used in the tables:

ITE =	In-The-Ear
BTE =	Behind-The-Ear

Table 5.4.1 Results of GSM tests in Denmark

GSM immunity category	I	II	III	IV
Field strength (V/m)	> 80	> 30	> 10	< 10
Total	21682	50540	110105	133605
BTE	1050	18075	76640	99140
ITE	20632	32465	33465	33465
Total %	16	38	82	100
BTE %	1	18	77	100
ITE %	62	97	100	100

Table 5.4.2 Results of GSM tests in Norway

GSM immunity category	I	II	III	IV
Field strength (V/m)	> 80	> 30	> 10	< 10
Total	3539	9239	20708	23909
BTE	352	352	10973	14054
ITE	3187	8887	9735	9735
Total %	15	39	87	100
BTE %	3	3	78	100
ITE %	33	91	100	100

GSM

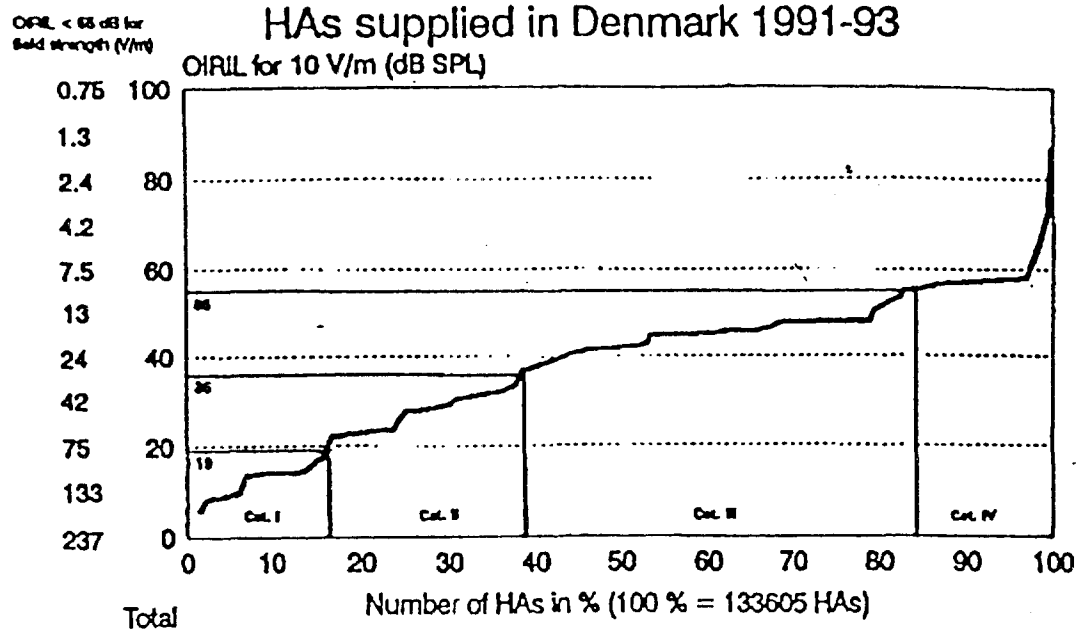


Fig. 5.4.1

GSM

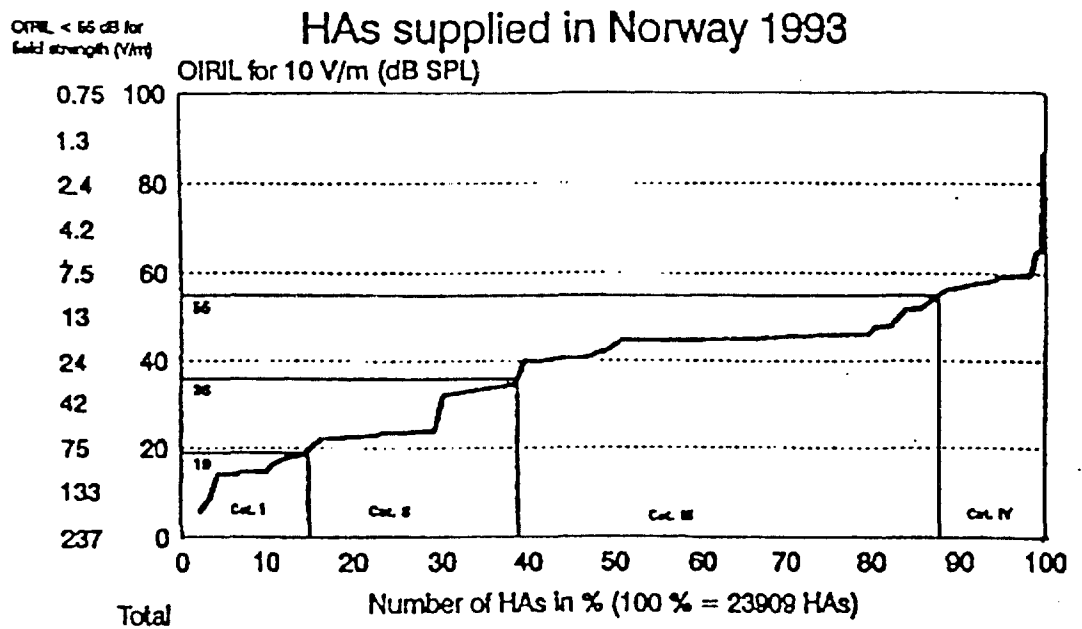


Fig. 5.4.2

DECT

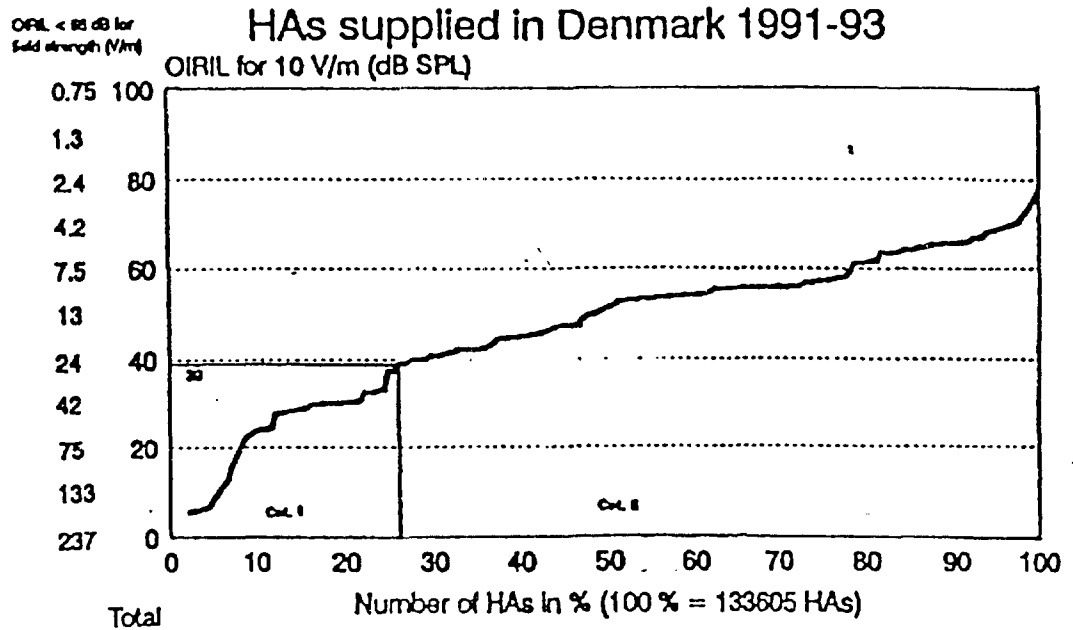


Fig. 5.4.3

DECT

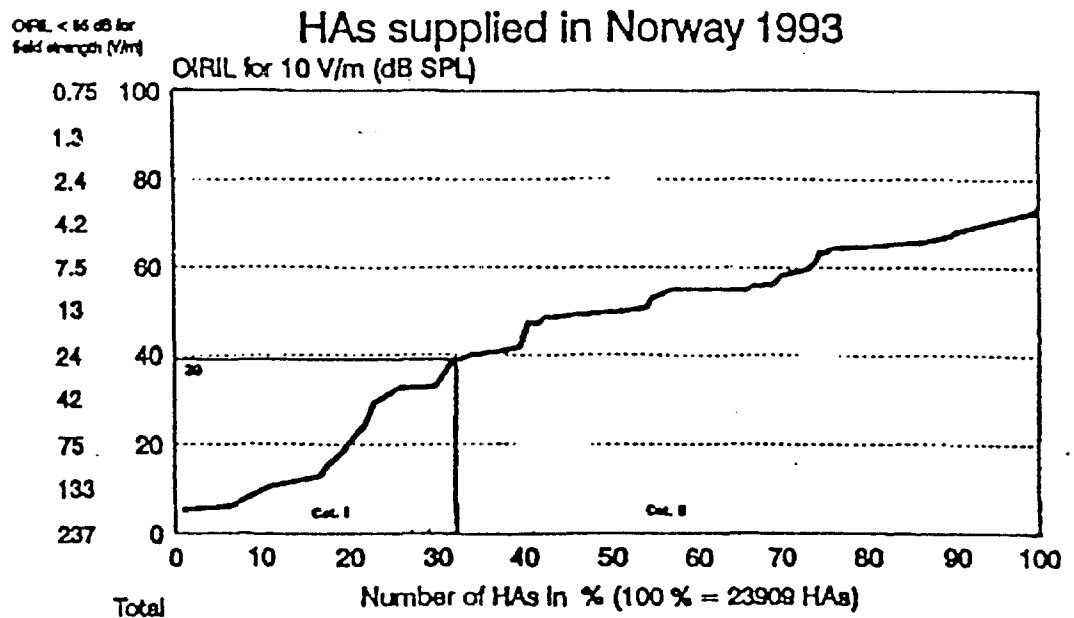


Fig. 5.4.4

5. 5 Discussion of measurement results

5.5.1 GSM

It may be seen from the tables that 82 % of hearing aids supplied by Danish clinics over the period 1991-1993 have such a degree of immunity that users are not liable to be disturbed by other persons using GSM telephones. As far as Norway is concerned, the corresponding figure is 87% of hearing aids supplied in 1993.

It would appear on the face of it that hearing aids supplied in Norway have a higher degree of immunity than Danish aids. However, the part of the study covering Norway concerns only hearing aid types supplied in 1993 and the assortment composition is consequently newer on the average, comprising also more ITE equipment than the Danish part of the study.

As regards the possibilities of using hearing aids together with a hand-portable 2 W GSM telephone, it may be seen from the table that users of hearing aids of categories III and IV, which total 62%, are not expected to be able to use their equipment together with such hand-portable GSM telephones.

It may also be inferred from the tables that hearing aids of the ITE type have the highest degree of immunity and that there is a great difference between these types and the BTE type. None of the ITE equipment supplied in Denmark or Norway is expected to display interference caused by other persons using GSM telephones.

Attention is drawn to the fact that even though the number of aids of the ITE type is increasing, the existing equipment of this type cannot be used to compensate for all kinds of hearing handicap. Not all equipment will therefore end up being ITE equipment.

It will be seen from the tables that there is a group of hearing aids, totalling 22%, of which some may be used together with a hand-portable GSM telephone in the ear opposite that wearing the hearing aid, provided that only one ear is wearing a hearing aid and the hearing faculty of the other ear is sufficient. No information is available to the Working Group on the proportion of the country's hearing aid users that can use this possibility.

It may also be mentioned that today there are 0.8 W hand portable GSM telephones giving a field strength which is 4 dB lower than the field strength of a 2 W hand-portable telephone. Reduction of the field strength by 4 Db causes a reduction of the interfering signal of 8 Db. Accordingly, hearing aids whose OIRIL just exceeds 55 Db when a 2 W GSM telephone is in operation may be used together with a 0.8 W GSM telephone. It cannot be expected, however, that there will be the same coverage with a 0.8 W hand-portable GSM telephone as with a 2 W telephone, since the GSM networks were designed for the use of 2 W hand-portable telephones. In urban areas with a high degree of coverage a fair result may probably be achieved, however.

with hearing aids, it was also decided to leave it to the individual manufacturers to seek advice on increased immunity of their equipment.

Typically, interference originates in those parts of the circuits where the signal level is low and the gain is high, e.g. in the microphone amplifier or the microphone itself. Preliminary results indicate that interference from systems working in the 1800 MHz area will be more powerful for the same field strength.

Essentially, there seem to be three methods to achieve immunity:

1. Reduction of the size of the equipment. The smaller the equipment, the higher generally the degree of immunity. Typically, ITE equipment has a higher degree of immunity than the bigger BTE equipment. Especially the length of the cabling connecting microphone and amplifier seems to be important. For various practical reasons it is not possible to reduce equipment arbitrarily.
2. The use of decoupling elements as capacitors in parallel with the sensitive inputs or inductances inserted in the cabling between sensitive circuit elements may increase immunity. It is hard, however, to say anything precise about where to position the components for maximum effect and how great this effect will be. It may be difficult to find the space in existing hearing aids for supplementary components and, besides, inserting these may change the other properties of the circuits.
3. Shielding the equipment by fitting a tight, metallic shield around the entire amplifier. This method may be quite effective but also involves certain practical problems. For one thing, it is difficult to coat the ITE equipment, which has been adapted to the individual user's ear, with a thin metal layer. The risk of undesirable short circuits between the shield and parts of the circuits is considerable, particularly in cases of condensed moisture being present.

As will be seen, the modification of existing constructions may be very difficult and/or costly. In new constructions, it will be possible to ensure a higher degree of immunity through the use of one or several of the above methods.

It is highly uncertain, however, whether it is possible with the means described to produce BTE equipment with a degree of immunity to allow the use of hand-portable 2 W GSM terminals and DECT telephones. ITE equipment can achieve a higher degree of immunity but does not cover all forms of hearing handicap.

6.2 Methods of remedying interference from DECT

Interference seems to occur only in relation to use of the DECT system. Apart from improving the immunity of the hearing aid and as the output power cannot be reduced, interference may be limited by increasing the distance between the hearing aid and the DECT transmitter, whether this is a base station or a portable unit.

It is important to note, therefore, that the workplace of the hearing aid user should not be close to a base station but if possible it should be situated at a distance of over 2-3 m.

8. PROMOTION OF INTERNATIONAL STANDARDIZATION WORK

8.1 Preparation of a product standard for hearing aids

Prompted by the Working Group's Report dated 10 June 1993, the Minister for Communications and Tourism at the time, Arne Melchior, contacted EU Commissioner Martin Bangemann to ensure that preparation of a product-specific EMC standard for hearing aids was promoted.

Mr. Bangemann reacted swiftly by giving highest priority to the existing mandate held in this field by the European standardization organization, CENELEC.

Within the international standardization organization IEC, the UK National Committee in the spring of 1993 tabled a proposal to start preparing a similar standard. Very soon after it was tabled, this proposal was approved at a plenary meeting of the IEC and referred to working groups TC29/WG13 which are working with methods for the measurement of hearing aids, and SC77/WG7, working with EMC immunity to digital radio equipment.

In the autumn of 1993, a major project was started for the European hearing aids manufacturers' association, EHIMA, by the Technical-Audiological Laboratory and TD-L in order to specify measuring methods to determine the EMC immunity of hearing aids. The results of this project were immediately used by the IEC working groups and members of this Working Group participated in the project.

In December 1993, a meeting was arranged in Geneva of representatives of the relevant CENELEC and IEC bodies and it was decided that the results of the IEC working groups were to form the basis for the drawing up of a common CENELEC/IEC standard.

In February 1994, a working group meeting was held in Copenhagen in which participated representatives of the two IEC groups. At the meeting, a draft standard was agreed which has now been sent as Committee Draft to the national committees of the individual countries.

Comments on this proposal are expected to be dealt with at an IEC meeting in London in the autumn of 1994, and the final Draft International Standard is expected to be submitted for parallel voting in IEC and CENELEC in late 1994.

The setting up of the WGH Working Group, its work and the Minister's initiative in relation to the European Commission, together with Danish efforts in the relevant standardization bodies - all these factors acted together to achieve a swift sequence of events. This means that a final product standard may be expected already at the beginning of 1995.

8.2 Relationship between EMC Directive and Directive concerning medical devices

The EMC Directive (Directive 89/336/EEC) has been in force since 1 January 1992 and its transitional provisions will cease to apply on 31 December 1995. This means that from 1 January 1996, equipment, in order to be placed on the market, must fulfil the essential requirements of the Directive, such as compliance with harmonized EMC standards published

in the Official Journal of the European Communities with reference to the EMC Directive. Products complying with the essential requirements of the Directive may be supplied with a CE mark.

During the period when transitional provisions apply, there is freedom of choice to either have equipment fulfil the requirements to protection, which, in the case of hearing aids, are primarily the immunity requirements, or with the requirements to the product concerned in force on 31 December 1991. In the case of hearing aids, there were on 31 December 1991 no Danish rules governing their EMC properties. In case the old rules are chosen, hearing aids cannot be CE marked as far as the EMC Directive is concerned.

In June 1993, the Council of Ministers of the EU adopted a Directive on medical devices, including hearing aids (Directive 93/42/EEC, the second Directive concerning medical devices). This Directive enters into force on 1 January 1995 and its transitional provisions cease to apply on 14 June 1998 after which date medical devices may be placed on the market only if fulfilling the essential requirements of the Directive. Among the requirements to have been fulfilled in order for medical devices to be placed on the market is protection against EMC. If hearing aids fulfil the essential requirements of this Directive, they may be CE marked.

The Directive concerning medical devices is an Individual Directive which, as regards the equipment regulated under it, may invalidate other directives. As will be understood, from 15 June 1998, the EMC Directive is no longer in force with regard to medical devices.

During the transitional period of the Directive concerning medical devices, equipment may be placed on the market until 15 June 1998 according to the rules applying as at 31 December 1994. As, on 31 December 1994, the EMC Directive is still in the period where its transitional provisions apply, no essential requirements may be brought to bear from that date with regard to the EMC protection of hearing aids against EMC interference.

As on and from 1 January 1996, national standards with regard to EMC will lapse and be replaced by EU harmonized standards which will be converted to national standards, see Article 7 of the EMC Directive.

This implies that during the period 1 January to 14 June 1998, there will be freedom of choice to either have hearing aids CE marked according to the Directive concerning medical devices or according to the EMC Directive, with the endorsement that marking was made according to the requirements of the EMC Directive only, see below. As on and from 1 January 1996, therefore, essential requirements to the immunity of hearing aids will apply as provided by the EMC Directive.

8.3 CE marking

CE marking was introduced to indicate that a product whose properties are regulated according to one or several Directives, fulfil the essential requirements or the requirements to protection contained in the relevant Directives. The CE mark must appear on the product or on its packing.

Directive 93/68/EEC (the "CE Marking Directive") provides that if a product is regulated by more than one Directive, it is allowed, during the periods when the transitional provisions of these Directives apply, to supply the product with a CE mark even though not all requirements of the Directives have been fulfilled.

In this case, the CE marking must also contain information as to which relevant Directives have been fulfilled.

During the period until 15 June 1998, accordingly, it is allowed to supply hearing aids with a CE mark if they fulfil the requirements of the EMC Directive but in that case it must be indicated that the CE marking refers to the EMC Directive only.

9. CONCLUSION

The Working Group has accomplished its task as prescribed in the terms of reference. The result of its work appears both from the Report of 10 June 1993 and from this Report, both Reports with Annexes and Appendices.

It may be established that international standardization is underway and that the question of CE marking of hearing aids in relation to the provisions of the EMC Directive and the Directive concerning medical devices has been clarified.

It is submitted, therefore, that the Working Group discontinues its activities and is dissolved.

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EMC and the new Modulation Technologies.

Introduction.

The focus point of the 1980's for technological development was undoubtedly 'Information technology'. The 1980's saw the advent of the inexpensive PC-products, which quickly came within the purchasing capability of most people in the western world. With the PC's an unprecedented explosion-like development started.

Computing changed in a way, that nobody could have foreseen in the 60's. In short, computing turned 'Low-Cost' and became 'Personal'.

Now a decade later, a technological area, promising even farther reaching changes to our life and society is emerging. The technological focus of the 1990's is somewhat related to the 'Information Technology' revolution of the past decade, but still in most aspects, this new focus area is quite unique.

This key technology, that I have in mind, is 'Personal Communications'.

The new key technology of this decade share some of the same profound characteristics of the 'Information Technology' of the 1980's, namely:

- It will, in the coming decade, influence life and society to a degree, that nobody will be able to predict today.
- It is 'Personal', in the true sense of the word, and it will greatly enhance the productivity of most people

- It is 'Low-Cost'. Therefore most people in the western world will have the purchasing capability and interest to acquire 'Personal Communications' in one form or the other.
- It will enjoy widespread use, professionally on the job and privately.

The 'Personal Communications' revolution offers an additional key feature of extreme importance, which was not part of the information technology boost of the 1980's. 'Personal Communications' is truly portable.

Some of the earliest 'Personal Communications' platforms already known and available to us today: GSM, DECT and ERMES are fully mobile/portable with instant access to the system by a mere press on a button.

These platforms already combine to some extent the capability of data and speech. Future 'Personal Communications' platforms will be fully integrated data and speech units, containing speech telephone capability with high speed dataterminal and telefax functionality. All neatly implemented in extremely high scale integrated silicon chips, resulting into such a small overall size for the 'Personal Communications' terminal, that it can easily fit into the inside pocket of a business suit.

Such a 'Personal Communications' terminal is in effect a one-man mobile office. Combining a personal organiser, scheduler, spreadsheet- and word-processing, high-speed dataterminal with almost instant access to any database in the world, telefax and a "standard" speech telephone.

For a lot of very small businesses a fixed office will no longer be needed. The 'Personal Communications' revolution will allow some people to run a small, but successful business without having the financial burden of a fixed office. A situation the same people could not have exploited in the 1980's, as a fixed office were required, and their business opportunities could not cover these base costs.

'Personal Communications' will increase mobility in society in a geographical and social sense. 'Personal Communications' will extent the freedom of choice and the capabilities of the individual citizen.

A "Snake" in Paradise

But, is there really no "snake" in this technological paradise ? Yes, I am sorry to say so, regrettably there is indeed a "snake" in this modern-day Elysium. The "snake" I have in mind is EMC, or more correctly phrased: potentially lack of EMC.

Ironically, the "snake", i.e. the potential EMC-problems are linked to the very basic foundation of the 'Personal Communications' technology. This new and highly promising technology solidly rests upon two basic corner-stones. One being the low-cost, but still highly efficient and reliable mobile communications link of cellular radiosystems. The other is the efficient, high speed and extremely high scale integrated silicon chip, which is the basis for the small-size of the terminals.

Both corner-stones: radio transmitters and high speed silicon chips are regrettably prime sources of EMC-problems in other electronic equipment.

Compared to yesterday's mobile cellular radiocommunication, the potential severity of the EMC-problem is aggravated by the fact, that present, and especially the coming, 'Personal Communications' terminals will be very widespread in use and truly portable. Truly portable means, that they will be very close to the actual EMC-victim apparatus, and they will be relative stationary in use.

In short, the EMC-problem will appear more often, and when encountered, these EMC-phenomena will be longer lasting, as the terminals tend to move relatively slowly.

Finally, the advent of new modulation schemes can substantially deteriorate the EMC-scenario.

Telelaboratoriet.

My laboratory, Telelaboratoriet, is part of the Tele Danmark group, a mayor telecommunication service provider. In the Tele Danmark group we have for several years been fully aware of the EMC vs cellular terminal issue.

Telelaboratoriet is the expertise and knowledge center in the Tele Danmark group in the area of research, development and testing for the two involved technological disciplines: i.e. EMC and radiobased telecommunications. It is therefore only quite natural, that Telelaboratoriet started to look deeply into the EMC-issue of the modern 'Personal Communication' technology at a very early stage. In the passed years, we have accumulated some profound insight and knowledge relating to the special radio/EMC-issue.

With this presentation, I would like to share some of our findings with you, giving some emphasis to the effect on EMC-severity, that the selection of modulation will have for the environment. Much can be achieved, or lost, EMC-wise by selecting a suitable or unsuitable modulation scheme for a cellular radio system.

Cellular Radio System.

The new european cellular radio systems like GSM has already seized a considerable share of the market for mobile telephony. A similar success is expected for the DECT system which is just now coming into operation.

It did not take long, however, before it was recognized, that the use of the GSM telephones caused interference to other electronic equipment in their vicinity. The interference problems surprised many people, although this could have been anticipated.

There are indications from preliminary investigations that also the operation of DECT may cause equally serious interference problems.

The interference potential of the GSM and DECT transmitters is due to the TDMA scheme which effectively produces a 100% amplitude modulated radiated signal. The modulation frequency is system dependent, but in all cases the modulation envelope produces frequency components throughout the audio frequency spectrum.

The "old" analogue mobile telephones did not present similar problems. The radiated field strength may reach similar levels near the antenna, but due to the conventional frequency modulation or phase modulation which maintains a constant amplitude of the radiated field strength, the interference potential is far less severe.

The EMC problem.

The implementation of a Time Division Multiple Access (TDMA) scheme in GSM and DECT (and in many other cellular radio systems) has many advantages in terms of transmission quality, range, and spectrum utilization.

From the EMC point of view the sharing of a certain frequency band between many users by the allocation of a defined time slot to each communication channel has the unfortunate result, that the radiated power effectively appears as 100% square wave "amplitude modulated".

The details of this "non-constant envelope modulation" is system dependent. For GSM terminals the radiated power is pulsed with a ratio between ON and OFF times of 1:8. The repetition frequency is approximately 217 Hz. For DECT the duty cycle is 1:24 at approximately 100 Hz.

We focus our attention on the terminals rather than on the base stations because the distance to the base stations as a rule is sufficient to reduce the field strength to a tolerable level. The terminals will be used at much closer distances to other electronics: 1 meter or even less is realistic.

The square wave modulation envelope is demodulated in analogue circuits, e.g., amplifiers by audio rectification in the diode characteristics of the pn-junctions. The result is an audio signal with a large number of higher harmonics and a fundamental frequency determined by the separation between the time slots used by the terminal.

In analogue electronics with an audio output like telephones and hearing aids the result is an extremely annoying buzzing sound which very easily drowns the wanted signal.

Digital circuits may also be disturbed. The exact interference mechanism is however not so straight forward as in the analogue case and the problem needs to be studied further.

Interference problems already has been observed in several cases. The actual number of registered complaints is still relatively small. Based on the available information we expect that number will increase dramatically in the nearest future.

Which equipment types are disturbed

Analogue equipment is most likely to suffer from GSM disturbances, i.e., equipment with analogue transducers (thermometers, strain gages, accelerometers) or equipment with audio output (hearing aids, telephones, AM radios, HI FI equipment). We know that much of the equipment on the market has insufficient immunity.

Also digital systems may be disturbed, although a higher level of exposure may be necessary. It has been observed already that cash registers, taxi-meters, petrol pump meters, electronic weighing machines, detector circuits for remote control of TV-sets and garage door openers, telefax machines, etc, may be caused to malfunction.

GSM signals have caused jamming of on-line credit card terminals. After a short time the line was disconnected or the credit card was suspended due to repeated "unauthorized" attempts.

Some of the more dramatic cases involve car electronics. The prospects that cellular radios should interfere with the power steering, the ABS, the fuel injection or inflation of the air bags has stimulated the imagination.

The number of complaints will increase with the level of public awareness. Some of complaints of a somewhat curious character may be expected: an example is a case where the erection of a GSM antenna tower next to a fish farm was alleged to be responsible for an increase in the fish mortality rate.

It is common to all the interference cases except the more exotic ones, that the equipment suffering the disturbance was designed with no consideration of EMC.

The solution

The resources invested in the GSM, DECT and similar systems, in development of terminals and infrastructure, are so huge that the EMC problem can only be solved by ensuring sufficient immunity of electronic equipment being disturbed to allow it to co-exist with the cellular radios.

The EMC directive

In Europe this has been in fact a legal requirement as of medio 1992 at which time the EMC directive 89/336/EEC was implemented in the EEC countries. To allow member countries to finish the necessary national legislation and to give manufacturers ample time to adopt to the situation a transitional period was introduced by Directive 92/31/EEC. Consequently, conformance to the "Principal Protection Requirements" of the EMC directive is optional until Jan. 1. 1996.

The EMC directive covers virtually all electrical and electronic apparatus and states in article 4(b):

"The apparatus referred to in Article 2 (the scope) shall be so constructed that (....) the apparatus has an adequate level of intrinsic immunity of electromagnetic disturbance to enable it to operate as intended."

In other words, according to the directive equipment manufactured and sold for use in an ordinary electromagnetic environment, which includes cellular radio shall have "adequate" immunity.

This does not solve to-days problems. We return to the practical implementation of the EMC directive below. Here, we only remark that surprisingly few manufacturers have accepted the challenge, irrespective of the advantages of manufacturing for an open european market including EEC as well as most EFTA countries.

Restrictions on the use of cellular radios

A different "solution" is the banning on a general basis of the use of cellular (or other mobile) radios as has been enforced in certain vulnerable environments like hospitals, airplanes, telecom- and computer centres.

We recognize that it may be difficult, expensive or even impossible to immunize all equipment. In such special cases certain restricted, highly protected environments could be established. Such secured areas should not be larger than absolutely necessary and the supervision must be foolproof.

Otherwise it is only a matter of time before somebody somewhere inside forgets to switch off the pocket phone and receives a call...

Demonstration of conformity

Conformance to the principal protection requirements of the EMC directive may be demonstrated on the basis of a detailed evaluation of the design and construction file for each product by a "Notified body" i.e. a recognized 3rd party notified to the EEC Commission.

A more convenient approach involving reference to technical standards is possible according to the directive. Compliance with all relevant harmonized standards provides presumption of conformity to the principal protection requirements of the directive. A harmonized standard is a standard the reference of which has been published in the 'Official Journal of the EEC'.

Evidently this route requires that appropriate EMC standards are available. This is the case today for only few products. The standards making bodies, and for EMC this is primarily CENELEC and ETSI, are very busily engaged with the preparation of standards. Where at all possible by adaption of international (IEC) standards.

Telelaboratoriet take a very active part in this important work.

Hearing Aid Issue

The interference to hearing aids due to cellular radio services is unacceptable because it is a general matter of principle, that people with a handicap shall have access to all public services to the greatest extent possible, and they shall not suffer additionally due to public activities.

Below follows a brief account of how we at Telelaboratoriet have approached this specific problem.

Interference to hearing aids

The prevention of interference to hearing aids has top priority and many resources are invested in a solution.

The project is divided into 3 tasks:

- Firstly: the immunity of hearing aids on the market to-day shall be determined in order to establish the extent of the problem.
- Secondly: an acceptable level of interference should be found.
- Thirdly: a method and procedure for testing of immunity shall be specified.

Immunity of Hearing Aids

A large number of hearing aids of different types and from different manufacturers belonging to EHIMA (: European Hearing Instrument Manufacturers Association) was exposed to simulated GSM and DECT signals.

The signals were generated in an anechoic room by feeding an RF signal with pulsed carrier to a vertically polarized transmitting antenna. The duty cycle and repetition frequency of the pulsed RF signal and the RF carrier frequency was chosen as appropriate for the interfering source (GSM or DECT). The response of the hearing aids was recorded.

The Overall Input Related Interference Level, OIRIL¹, is used as a measure of the response.

The results showed a more than 40 dB spread in the measured acoustic response.

The unsaturated acoustic response was found to depend quadratically on the applied field strength. This is commonly observed in analogue audio equipment. It means that a factor of 2 increase of the applied field strength produces an increase in the response with a factor of 4.

The electromagnetic field strengths that may actually be encountered in the vicinity of mobile and portable radio telephones are given in Table 1. The field strength depend on the power rating of the terminal. GSM terminals are classified according to their maximum available power. Most terminals belong to the 0.8 Watt, 2 Watt, 5 Watt, or 8 Watt classes. Table 1 states the distance from the terminal where a certain field strength is found.

Table 1

Field strength	Distance	
	2 Watt GSM	8 Watt GSM
1 V/m	10 meter	20 meter
3 V/m	3.3 meter	6.6 meter
10 V/m	1 meter	2 meter
30 V/m	0.3 meter	0.7 meter

¹ The OIRIL is the rms acoustical respons referred to the input by correcting the measured output spectrum for the frequency dependent gain of the hearing aid.